Synthetic biology

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Editorial Introduction

Synthetic biology: Making Biology into an Engineering Discipline

With this special issue, we hope to open up a conversation with readers of *Engineering Studies* about the emerging field of synthetic biology. Despite the name synthetic *biology,* the guiding ambition of practitioners in this field is to turn biology into an engineering discipline by bringing engineering principles and practices from more established fields of engineering into the world of biotechnology.[1] There is a rich and growing body of critical literature on synthetic biology, but it has yet to engage substantially with engineering studies. This collection of papers strives to open up a set of questions for reflection and empirical investigation in what we see as an intriguing space emerging in the interstices between science studies and engineering studies.

The term 'synthetic biology' can be traced back to the early 20th century,[2] but the past 10-15 years have seen a concerted attempt to forge a new discipline around a particular understanding of how to work with biology.[3] Although practitioners and observers alike refer to synthetic biology in ways that capture a variety of research trajectories,[4] the dominant strand — and our focus in this collection of papers — draws heavily on existing engineering, defining synthetic biology as "the design and construction of new biological parts, devices, and systems," and "the re-design of existing, natural biological systems for useful purposes."[5] Proponents of synthetic biology distinguish their work from the genetic engineering methods that have been developed over the past 40 years, and typically describe genetic engineering as an *ad hoc*, craft-like practice, rather than 'proper' engineering.[6] Synthetic biologists position themselves as building an enterprise that will deliver where genetic engineering has failed. This estrangement from established science serves to demarcate synthetic biology and assert its novelty. It also works as a rallying cry and mission statement: synthetic biology will 'make biology easier to engineer.'

[1] Endy, "Foundations for Engineering Biology," 2005; Baker et al, "Engineering Life," 2006.
[2] Leduc, *La biologie synthétique*, 1912.
[3] Nature, "Ten Years of Synergy," 2010.
[4] Editoral, "Synthetic Biology," 2009; O'Malley et al, "Knowledge-Making Distinctions," 2008.
[5] www.syntheticbiology.org.
[6] See e.g. Heinemann and Panke, "Synthetic Biology," 2006.

Synthetic biologists routinely refer to a set of 'engineering principles'[7] that inform and structure their goals and methods. More generally, these principles underlie a particular philosophy of practice and support a set of normative commitments. Core among the engineering principles identified is *abstraction*,[8] the pragmatic simplification of complexity and the use of representational tools to facilitate design practices. Synthetic biologists also emphasize the *modularity*[9] of biological systems and see this characteristic as enabling the construction of *functional biological parts*[10] (typically DNA sequences that encode particular functions). Working with biological parts is intended to help compartmentalize design problems, simplify fabrication, and rapidly enable circuits with higher-level functions to be constructed. The principle of *standardization*[11] complements the use of functional modules. Genetic parts are to be standardized, functionally isolated, and capable of easy combination into complex 'devices,' 'systems' and 'circuits.' (Synthetic biologists frequently compare biological parts with electrical circuit components and with Lego® bricks.) Finally, standardized biological parts should be subject to *quantification.*[12] That is, individual components should be characterized in measurable terms, and should display calculable, predictable performance.

Such engineering principles are upheld in support of synthetic biology's celebration of utility and its orientation towards industrialization. Synthetic biologists aim to produce real-world applications (as shown in the papers by Balmer and Molyneux-Hodgson and by Mackenzie). Industrial actors are starting to make significant investments in synthetic biology, and also serve as advisory board members of synthetic biology research centres. The rapidly growing International Genetically Engineering Machine (iGEM) undergraduate competition (discussed by Frow and Calvert) is also focused on possible applications of synthetic biology, and tasks teams with dreaming up novel applications that can be constructed from a toolbox of simple genetic components. This utility- and application-oriented focus of synthetic biology reflects the desire of many synthetic biologists to establish a new

[7] Endy, "Foundations for Engineering Biology," 2005.
[8] Endy, "Foundations for Engineering Biology," 2005.
[9] Hartwell et al, "From Molecular to Modular Cell Biology," 1999; Sauro, "Modularity Defined," 2008.
[10] Endy and Arkin, "Standard Parts List," 1999.
[11] Arkin, "Setting the Standard," 2008; Canton et al, "Refinement and Standardization," 2008.
[12] Arkin, "Setting the Standard," 2008; Chopra and Kamma, "Engineering Life," 2006; De Lorenzo and Danchin, "Synthetic Biology," 2008; Purnick and Weiss, "Second Wave," 2009.

engineering discipline focused on biological substrates, and they regularly associate synthetic biology with material successes in other, more established fields of engineering.[13]

If we consider *how* these synthetic biologists are setting about the goal of 'making biology easier to engineer,' their activities to date fall into two main strands: building (relatively small) biological circuits from genetic componentry to produce useful molecules (e.g. biofuels) or to perform specific functions (e.g. detecting arsenic levels in water), and developing hardware, 'wetware' and software tools that assist in the practices of modelling and building with biology.[14] Thus far, the research community has met with fairly limited success in turning principles into practice.[15] A key challenge they face is having incomplete knowledge of the biological systems they are working with, and they also have to deal with the unpredictability of working with living, evolving systems. Furthermore, the field of synthetic biology is currently an unsettled amalgamation of practitioners with diverse traditions, research foci, and epistemic and methodological commitments. They include biologists, chemists, physicists and all manner of engineers. As several of the papers in this collection show, the trope of 'real' engineering is perhaps best understood at this stage as an idealization, a construct used to emphasize novelty, to direct research and to shape a nascent field. It offers a model to emulate, a commitment to make, and an axis around which a community can form (Gieryn, 1983). The engineering ideal is certainly influencing epistemic, ontological, methodological, pedagogical, regulatory, ethical and economic dimensions of synthetic biology, but in practice this is not through a straightforward imposition of engineering onto biology.

The papers in this special issue are united through a focus on the practices of synthetic biology, and explore how the engineering ideal is being negotiated in real time and space, and in relation to material constraints, disciplinary commitments, and broader economic and geopolitical concerns. The contributors to this special issue are all researchers in science and technology studies who have become involved with synthetic biology in recent years. This is in part owing to the growing demand for involving social scientists in synthetic biology programs in the UK and, in Pablo

[13] Arkin, "Setting the Standard," 2008.
[14] Liebler and Elowitz, "Synthetic Oscillatory Network," 2000; Keasling et al, "USPTO Patent Application," 2007; Knight, "Idempotent Vector Design," 2003; Wang *et al*, "Programming Cells," 2009.
[15] Kwok, "Five Hard Truths," 2009

Schyfter's case, the USA. Most of us are embedded in synthetic biology communities and research projects, working alongside practicing synthetic biologists, and often funded through the same grants. This has given us high levels of access to the field, while simultaneously raising a number of methodological and conceptual challenges for our research (Balmer and Molyneux-Hodgson).[16]

Broadly speaking, our contributions seek to identify and examine the ways in which engineering is being brought to bear upon the world of living things. The assembled papers explore a diversity of sites in which synthetic biology is being constructed, including the academic laboratory (Schyfter, Finlay), the iGEM undergraduate competition (Frow and Calvert), waste water treatment facilities (Balmer and Molyneux-Hodgson), and the industrial realm of biofuels (Mackenzie).

Schyfter's epistemological study compares current metrological research in a synthetic biology laboratory with Vincenti's classic work on aeronautical engineering in the early 20th century. Like Vincenti, Schyfter argues that engineering knowledge cannot be understood in isolation from engineering practice, and he shows how both aeronautical engineers and synthetic biologists use the trial-and-error method of parameter variation in designing their technological artifacts. He argues that in both cases we see the compound making of knowledge, artifacts and disciplines.

Finlay's ethnographic study is also based in the laboratory. She traces rhetorics of engineering in a large synthetic biology research centre, and reveals in detail how the practice of engineering with biology is much messier than its rhetorical presentation would imply. Like Schyfter, she argues that aligning synthetic biology with engineering is an act of discipline-building, working in part to distinguish synthetic biology from molecular biology and to legitimize the field.

Frow and Calvert also draw attention to the disjuncture between idealized notions of engineering and the realities of synthetic biology work. Their research site is the rapidly growing iGEM competition in synthetic biology; by following student teams during this summer competition, they show how key engineering principles are being negotiated in practice, and explore how the identities of synthetic biologists are being formed through this unusual pedagogical initiative.

[16] The contributors to this special issue have also participated in a series of workshops funded by the UK Economic and Social Research Council on 'Synthetic Biology and the Social Sciences' (http://www.genomicsnetwork.ac.uk/seminarseries/).

The final two papers in this collection orient our attention to some of the industrial applications promised by synthetic biology. Balmer and Molyneux-Hodgson offer an intriguing comparison of the clean, white and hygienic realm of the laboratory-based synthetic biologist with the 'real world' of sewage and waste in the water treatment facility of the process engineer. They show that bacteria are ascribed very different meanings across these two sites (from vulnerable organism to dangerous threat), and argue that the very ontologies of 'engineer' and 'bacteria' should be understood as mutually constituted through context-specific practices.

Finally, Mackenzie's contribution explores a key industrial application touted for synthetic biology, that of next-generation biofuels. His concern is with the 'economic calculus' of synthetic biology — with the justifications and stories used to link economic and metabolic processes, which end up situating synthetic biology within a much broader social and geopolitical context. He argues that this calculus adds additional layers of opportunities and constraints to the laboratory-based engineering principles that have been the focus of so much attention within the synthetic biology community. Through his paper we see how the relatively abstract promises of engineering biology can become entangled with technologies, infrastructures and markets.

Together, these papers begin to trace the diversity of processes and practices involved in constructing synthetic biology as a branch of engineering. Adopting a range of methods and research sites, each of the contributions shows that it is not straightforward to make biology into an engineering discipline. Rather, longstanding practices of engineering are being adapted to and informed by the realities of working with and on biological substrates. Different disciplinary understandings of how to derive meaning and value and broader geopolitical and market forces are all at work in this process. We suggest this collection of papers raises a number of questions and avenues for further exploration. They draw our attention to rhetorics of engineering, design and control, and how these are manifest in different disciplinary communities and scientific projects. We are also pushed to consider the materiality of engineering, and how theories and practices may be shaped by the properties of the substrates being engineered; such investigations may in turn further our understanding of more conventional engineering disciplines. A focus on synthetic biology in-the-making also raises questions about the birth and growth of new fields, and practices of identity formation and meaning-making in increasingly interdisciplinary settings. Finally, differences in biological and engineering imaginations of the utility and broader social and ethical dimensions of synthetic biology are opened up, and offer potentially interesting opportunities for study and intervention. We believe that researchers from both science studies and engineering studies have much to contribute to our understanding of the emergence of fields like synthetic biology (particularly as growing numbers of engineers, physicists, computer scientists and mathematicians turn to biological sciences), and also much to learn from one another. Synthetic biology may serve as a space to develop, jointly, new tools for the study of science and engineering.

Pablo Schyfter, Emma Frow and Jane Calvert

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